

Testing the effect of new constructions of swirl insert on spray parameters

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Abstract

The paper presents the concept of new swirl inserts. An empty two-phase swirl flow atomizer, and three atomizers with inserts were designed, manufactured and tested. The tested atomizers did not differ in terms of their geometric dimensions, with the only variable being the type of swirl chamber filling. Flow resistance and spray angle values were analysed for all the evaluated structures. It was shown that the presence of a swirl insert did not significantly increase flow resistance, but instead resulted in larger spray angles. Taking into account the values of flow resistance and spray angles, the best design solution turned out to be the set of inserts No. 2.

Keywords

atomizer design, swirl inserts, flow resistance, spray angles

1. INTRODUCTION

Atomizers are some of the most important elements in many industrial processes (Nasr et al., 2002). The construction of an atomizer has a direct impact on its effectiveness and efficiency. Over the last few decades, there have been significant changes in their design, which in turn have allowed for improvements in their performance and reliability (Gad et al., 2022; Jedelský et al., 2021). In the era of technological progress and improvements of process equipment, modifications to the design of atomizers are an extremely important issue. The constant development of new materials, technologies and production processes creates opportunities for new and more advanced design solutions of atomizers. This in turn allows for their better performance, precision and lower environmental impact. Modifications to the design of atomizers are also necessary in order to meet the changing needs and individual requirements of customers. Tailoring the design of atomizers to specific customer needs can be crucial for staying competitive on the market. These modifications include the dimensions and shapes of the outlet (Cui et al., 2017); the ratio of the diameter of the atomizer's chamber to the diameter of the outlet; the ratio of the length of the outlet to its diameter (Rashad et al., 2016); and the number, geometry and shape of the inserts (Khani Aminjan et al., 2021; Nonnenmacher and Piesche, 2000). Progress in this area will continue in order to meet the growing demands of the market.

One of the widely used and studied types of atomizers are swirl atomizers (Belhadef et al., 2012; Chu et al., 2008; Sun et al., 2018), in which the liquid is rotated before exiting the nozzle. They are designed to generate a swirling conical stream of liquid that eventually breaks down into a film and droplets under the combined action of external and internal forces (Wang et al., 2015). The swirl flow is usually generated by injecting liquid tangential to the swirl chamber, or by using a swirl element located inside the atomizer when axially introducing the liquid, i.e. the so-called swirl insert. The purpose of swirl inserts in atomizers is to increase energy and to homogenize the atomized medium. These inserts create micro-turbulences that break up the liquid into smaller droplets, allowing for better distribution of the medium at the spraying point. The shape and positioning of the swirl inserts vary with regards to the model of the atomizer and the type of medium to be sprayed. Depending on the individual needs and requirements of a given application, inserts can also have different sizes and configurations.

Nonnenmacher and Piesche (2000) performed numerical analysis and test studies of a swirl atomizer with an insert (with spirally shaped grooves), the number and cone angle of which were constant. The analyzed liquids were water and a mixture of water and glycerin. Khani Aminjan et al. (2021) investigated the effect of the number of spiral inserts and their different geometries in a swirl chamber on the spray angle, discharge coefficient and droplet diameters in a swirl



atomizer. The analysis was conducted using numerical and experimental methods. The obtained results showed that (at a constant flow rate) with an increase in the degree of torsion of the spiral paths, the radial component of the velocity increases, which in turn reduces the diameter of the droplet. It was also observed that an increase in the torsion of the inserts (reducing the angle of the paths) had the greatest impact on the spray angle in the first spraying phase, causing it to significantly increase. This also affected other parameters, i.e. the discharge coefficient, the thickness of the liquid layer, and the droplet diameters (causing their reduction).

Despite numerous advantages that can be obtained from the use of swirl flow atomizers, an even better atomization effect can be obtained by introducing a gas phase into the atomizer. The introduction of gas into the atomizer increases the spray angle and reduces the size of the liquid droplets, which can lead to a more uniform and even spray (Li et al., 2012; Mohammadi et al., 2021; Prakash et al., 2014).

The effectiveness of the applied design solution is mainly assessed on the basis of the parameters of the spray stream, the most important of which are: pressure drop, spray angle, mean droplet diameter, and droplet size distribution (Guan et al., 2018; Lan et al., 2014).

The aim of the work was to design three different inserts in order to increase the efficiency of the spraying process in two-phase swirl flow atomizers, and also to analyze the impact of the presence of an insert and its construction on the parameters of the atomized stream.

2. METHODOLOGY

The two-phase swirl flow atomizers and three types of fillings were designed in the Autodesk Inventor Professional 2023 program. Ready-made models of the atomizers and swirl inserts were created using 3D printing technology (FDM technology) and da Vinci 1.0 Profesional 3D printer. Reinforced ABS fiber (acrylonitrile butadiene styrene copolymer), which has high mechanical strength and is resistant to high temperatures, was used in the applied technology.

Pressure-swirl atomizers with a conical bottom and a cylindrical outlet (with a diameter of $d_o = 0.0025$ m) were designed. The general construction and dimensions of the atomizers were the same in each case.

The atomizers consisted of two parts connected by flanges. In the upper cylindrical part there was a liquid inlet nozzle with a diameter $d_{pl} = 0.004$ m, while in the lower conical part there was a gas inlet nozzle with a diameter $d_{pg} = 0.0025$ m. The inside diameter of the atomizer was $D = 0.03$ m.

They only differed in terms of the shape of the swirl insert. Three different insert designs were used, as shown in Figures 1–3. Figure 4 presents 3D models of all the swirl inserts, and Figure 5 presents a 3D model of the atomizer.

The test stand consisted of the tested atomizer, liquid and gas rotameters by Krohne Messtechnik GmbH&Co KG type VA 40 (with Italinox poppet valves), a MEGA 350-100 D Metabo compressor, and a Mierzator 5000 flow and pressure meter (designed and made by a graduate of the Poz-

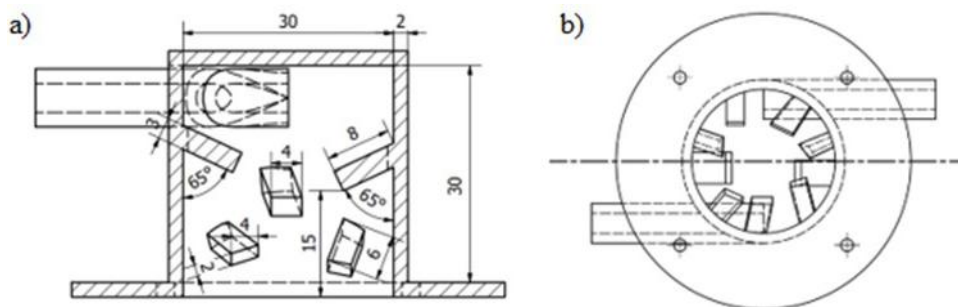


Figure 1. The chamber of the atomizer with inserts No. 1: a) cross-section, b) bottom view.

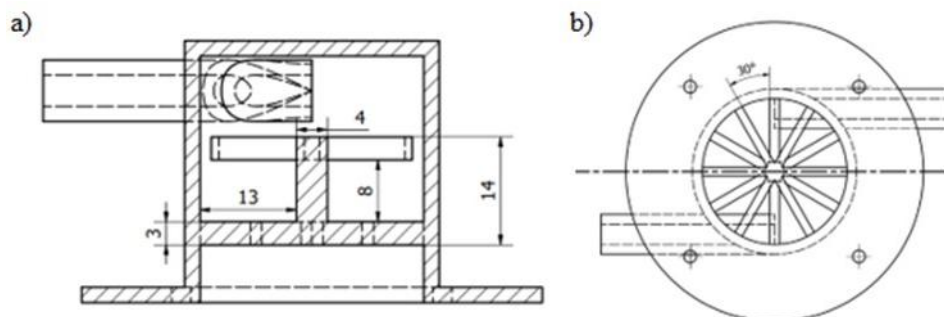


Figure 2. The chamber of the atomizer with inserts No. 2: a) cross-section, b) bottom view.

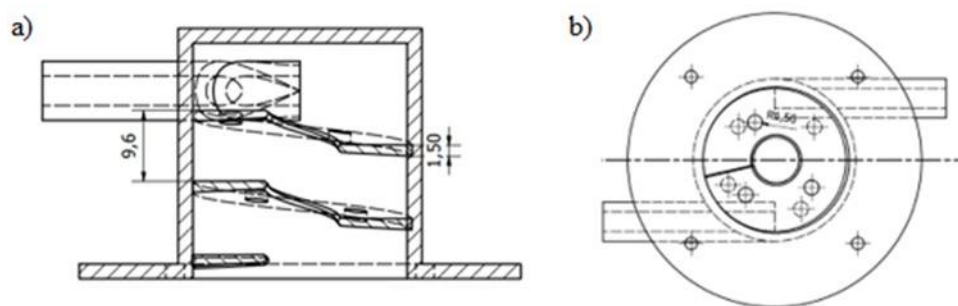


Figure 3. The chamber of the atomizer with inserts No. 3: a) cross-section, b) bottom view.

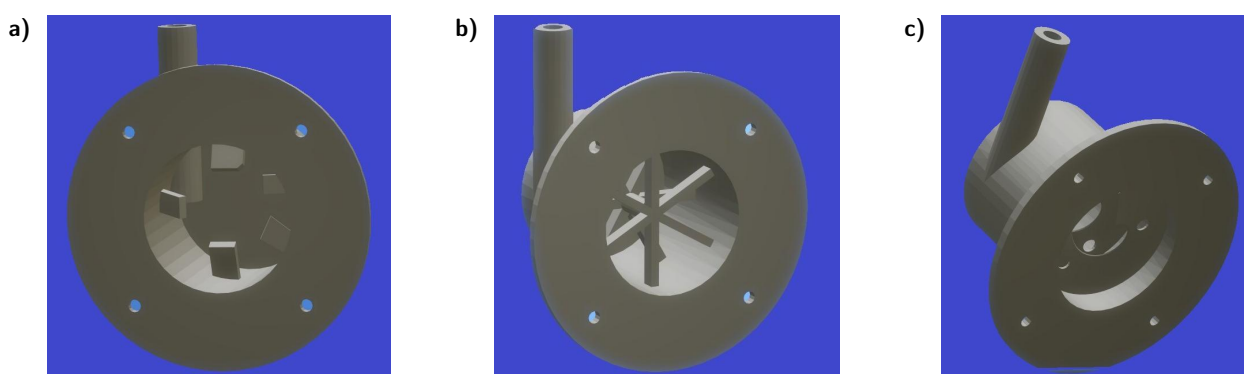


Figure 4. 3D models of the swirl inserts: No. 1, b) No. 2, c) No. 3.

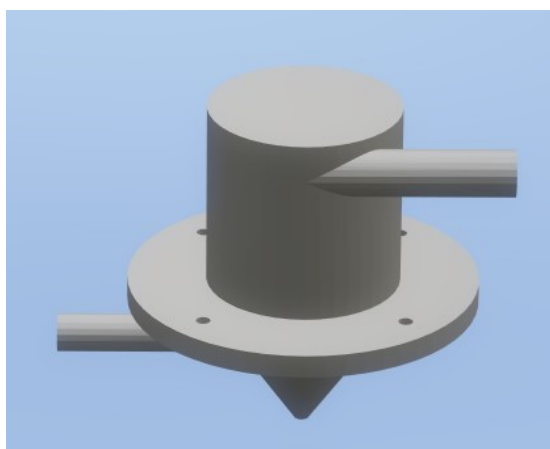


Figure 5. 3D model of the pressure-swirl atomizer.

nań University of Technology) that was connected to a computer, a Canon EOS camera 1D Mark III, and the DrelloScop 210 strobe by Drello Ing. Paul Drellwell (with a lamp type LE 210-01 that had a flash energy of 9 W·s and a flash time of 10 μs). The tests were carried out for the volumetric flow rate of tap water Q_w ranging from $2.78 \cdot 10^{-6} \text{ m}^3/\text{s}$ to $2.78 \cdot 10^{-5} \text{ m}^3/\text{s}$, and the volumetric flow rate of air Q_a ranging from $1.39 \cdot 10^{-4} \text{ m}^3/\text{s}$ to $5.56 \cdot 10^{-4} \text{ m}^3/\text{s}$ in a temperature of 20 °C.

During the tests, a series of photos of the sprayed stream was taken. The atomizer, which was fixed using a clamp, was set

against a black background at a constant distance of 43 cm from the camera lens. Spray images were taken under stable operating conditions with an ISO sensitivity set to 500, and an exposure time of 1/500 s. ImageJ was then used for the analysis and for measuring the spray angles.

3. RESULTS

The tests were carried out for an empty atomizer, and then for an atomizer with three types of inserts that had a different construction. Pressure drops for the atomizers with an insert were greater than in the case of the empty atomizers, but this difference was not significant, as shown in Figure 6. With an increase in the volumetric flow rate of liquid and gas, there was also an increase in the pressure drop. The highest values of pressure drop in the atomizers with inserts were obtained for the atomizer with the set of inserts No. 1, whereas the smallest pressure drops were obtained for the atomizer with the set of inserts No. 3. The pressure drops for the atomizer with the set of inserts No. 2 were lower than for the atomizer with the set of inserts No. 1, but higher than those obtained by the atomizer with the set of inserts No. 3. For example, for $Q_w = 2.78 \cdot 10^{-5} \text{ m}^3/\text{s}$ and $Q_a = 4.17 \cdot 10^{-4} \text{ m}^3/\text{s}$, the following pressure drops were obtained: $\Delta P = 110000 \text{ Pa}$ (empty atomizer), $\Delta P = 116000 \text{ Pa}$ (atomizer with the set of inserts No. 1), $\Delta P = 114000 \text{ Pa}$ (atomizer with the set of inserts No. 2), $\Delta P = 111000 \text{ Pa}$ (atomizer with the set of inserts No. 3).

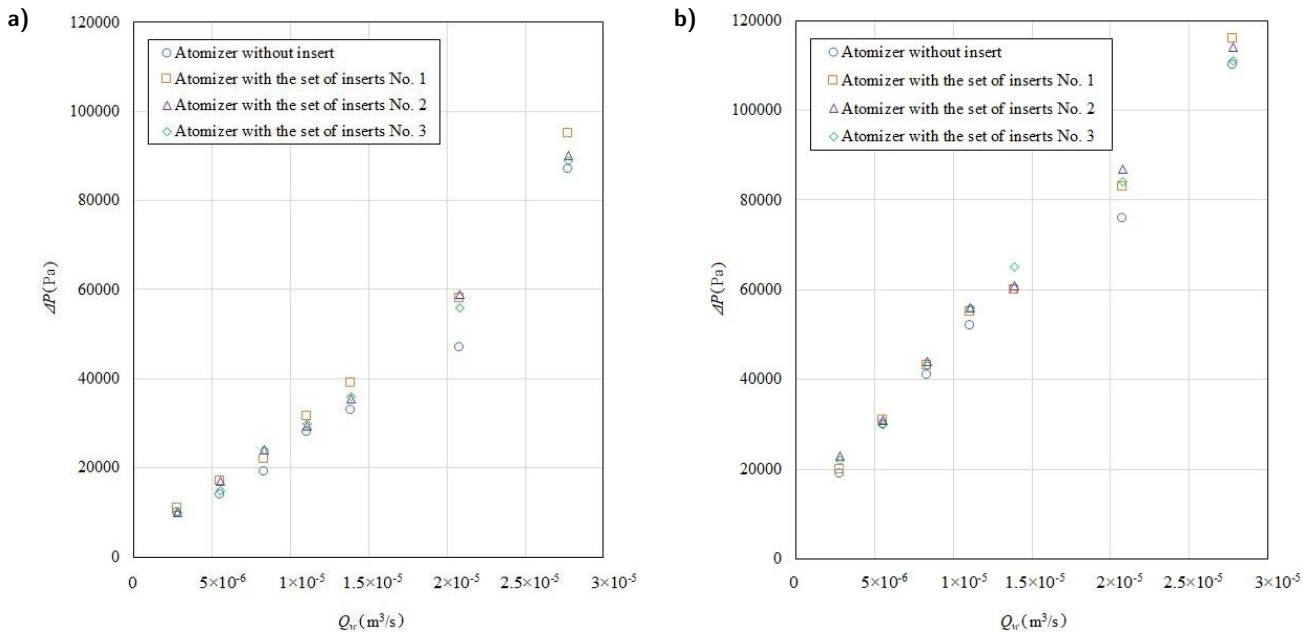


Figure 6. The dependence between the pressure drops and volumetric flow rate of water for all the swirl inserts: a) in the case of the volumetric flow rate of air $Q_a = 2.78 \cdot 10^{-4} \text{ (m}^3/\text{s)}$, b) in the case of the volumetric flow rate of air $Q_a = 4.17 \cdot 10^{-4} \text{ (m}^3/\text{s)}$.

Figure 7 shows exemplary results of the spray angles for the empty atomizer and for the atomizer with three types of swirl inserts. Generally, the largest spray angles were obtained for the atomizer with the set of inserts No. 2, with the largest value being approx. $\alpha = 40^\circ$. It was achieved for the gas flow rate of $Q_a = 2.78 \cdot 10^{-4} \text{ m}^3/\text{s}$. The atomizer with the set of inserts No. 1 had slightly smaller spray angles than the atomizer with the set of inserts No. 2. The spray angles of the atomizer with the set of inserts No.3 were the smallest

out of all the atomizers with the inserts. The smallest values of the spray angle were obtained for the empty atomizer. For all the analyzed atomizers, the spray angles increased with an increase in the volumetric flow rate of the liquid and gas.

There are slight differences in the values of pressure drops and spray angles when using particular types of inserts. The most favourable atomization results, i.e. the largest angles, were obtained for the atomizer with the set of inserts No. 2.

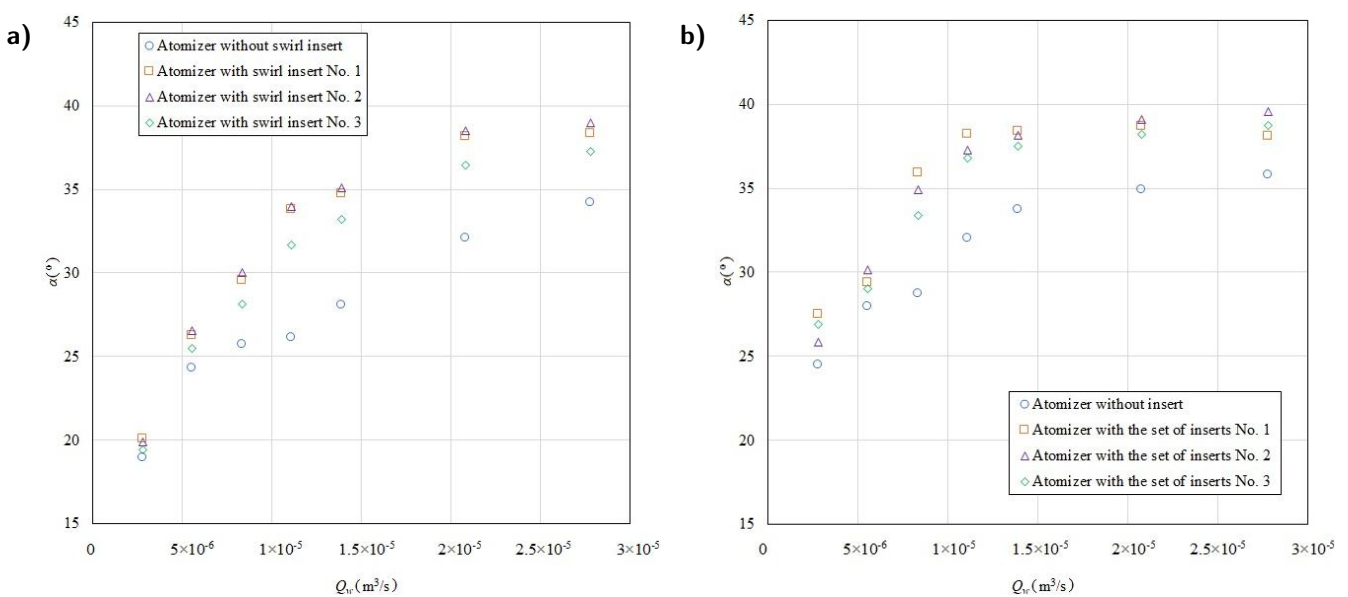


Figure 7. The dependence between the spray angle and volumetric flow rate of water for all the swirl inserts: a) in the case of the volumetric flow rate of air $Q_a = 1.39 \cdot 10^{-4} \text{ (m}^3/\text{s)}$, b) in the case of the volumetric flow rate of air $Q_a = 2.78 \cdot 10^{-4} \text{ (m}^3/\text{s)}$.

4. CONCLUSIONS

The paper presents the design of swirl inserts that have a new construction. In order to compare the operation of an atomizer without swirl inserts and an atomizer with inserts (with a different construction), pressure drops and spray angles were determined. Based on the obtained results, it was shown that the presence of a flow swirl insert affected the value of resistance during the flow of liquid through the atomizer, but these values were not significantly high when compared to the empty atomizer. Differences in the values of pressure drops for the atomizers with inserts were small (the maximum differences were approx. 8%). The spray angle values increased due to the use of swirl inserts. The greatest changes were observed for the volumetric water flow rate of $Q_w > 8.33 \cdot 10^{-6} \text{ m}^3/\text{s}$. The spray angles obtained for the atomizers with inserts of a different construction did not differ significantly, but, for most analyzed cases, the highest spray angles were observed in the case of the atomizer with the set of inserts No. 2. Taking into account the size of the pressure drops and spray angles, the set of inserts No. 2 turned out to be the most advantageous solution. An application of the atomizer with the set of inserts No. 2 allows to obtain a spray angle of $\alpha = 40^\circ$, at a pressure drop of $\Delta P = 90000 \text{ Pa}$. For this design solution, the highest spray angle values were obtained compared to other nozzles, and lower pressure drop values were obtained than for the atomizer with the set of inserts No. 3.

The obtained test results show that the introduction of additional structural elements is not necessarily associated with a significant increase of flow resistance, but it can positively affect the parameters of the atomized stream.

ACKNOWLEDGMENTS

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SYMBOLS

D internal diameter of atomizer, m
 Q volume flow rate, m^3/s
 d diameter of hole, m

Greek symbols

ΔP pressure drops, Pa
 α spray angle, $^\circ$

Subscripts

a air
 p port
 o orifice
 w water

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